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SWIR SKY-GLOW CLOUD CORRELATION WITH NIR AND VISIBLE CLOUDS: AN URBAN AND RURAL COMPARISON: POSTPRINT

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14. ABSTRACT
Between the wavelengths of the visible and the short wave infrared (SWIR), the glow of the sky from chemical radiance and absorption changes dramatically. Thus too, the structure and appearance of clouds change. By directly and simultaneously examining clouds in an urban and rural setting, we investigate the correlation between the appearance of clouds present in the SWIR, NIR, and visible. The experimental setup consists of two sensors, one a NIR to SWIR sensitive InGaAs array, and the other a visible CCD, both co-located on an AZ-EL mount, and both co-boresighted so that difference viewing angles of the sky are possible. The SWIR sensor is sensitive from 0.9 um to 1.7 um. The CCD sensor collects cloud images in the visible region. By making corrections for focal length and pixel size, the visible and SWIR data can be compared. After taking several nights of data in the urban environment of Albuquerque, NM, the entire system was then re-located to a rural location in Southern New Mexico.

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SWIR sky-glow cloud correlation with NIR and visible clouds: an urban and rural comparison

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ABSTRACT

Between the wavelengths of the visible and the Short Wave Infrared (SWIR), the glow of the sky from chemical radiance and absorption changes dramatically. Thus too, the structure and appearance of clouds change. By directly and simultaneously examining clouds in an urban and a rural setting, we investigate the correlation between the appearance of clouds present in the SWIR, NIR, and visible. The experimental setup consists of two sensors, one a NIR to SWIR sensitive InGaAs array, and the other a visible CCD, both co-located on an AZ-EL mount, and both co-boresighted so that different viewing angles of the sky are possible. The SWIR sensor is sensitive from 0.9 μm to 1.7 μm. The CCD sensor collects cloud images in the visible region. By making corrections for focal length and pixel size, the visible and SWIR data can be compared. After taking several nights of data in the urban environment of Albuquerque, NM, the entire system was then re-located to a rural location in southern New Mexico.

1.0 INTRODUCTION

Sky glow from chemical luminescence in the upper atmosphere has been observed at a number of different wavelengths [1-3]. In the short wave infra-red (SWIR) between 1.0 μm and 1.7 μm, it is due to emissions from hydroxyl radicals transitioning from excited rotational and translational states to lower energy states and emitting a SWIR photon in the process.

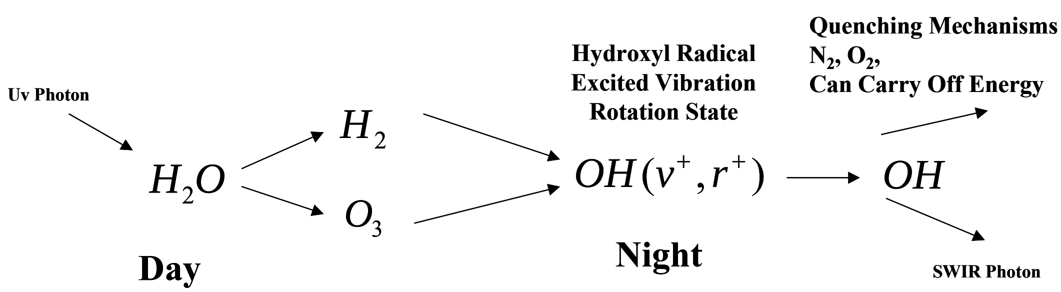


Figure 1.1 Synoptic Sketch of the Air Glow Process in the Infra-Red.

Figure 1.1 is a synoptic sketch of the air glow process for production of illumination in the SWIR band. Although the chemical reactions are very complicated, the overall effects can be summarized as follows. During the day, UV photons strike water molecules and initiate the production of hydrogen and ozone. At night, the hydrogen and ozone recombine and form the excited hydroxyl radicals with elevated vibration and rotational energy states. The molecules then transition to a lower energy state emitting a SWIR photon. The process can be quenched by other molecules, among them O_2 and N_2, which carry off the energy.

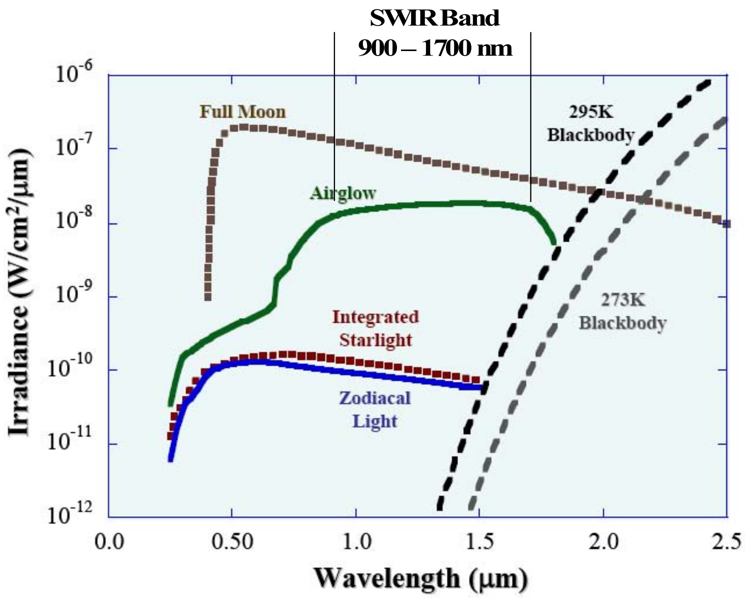


Figure 1.2 Night Time Illumination Sources

Figure 1.2 shows sources of night time illumination that can be used for imaging [1]. Of course the brightest source is the moon. When the moon is not out, or is obscured by clouds, figure 1.2 shows that sky glow provides a significant source much greater than thermal radiation in the SWIR band.

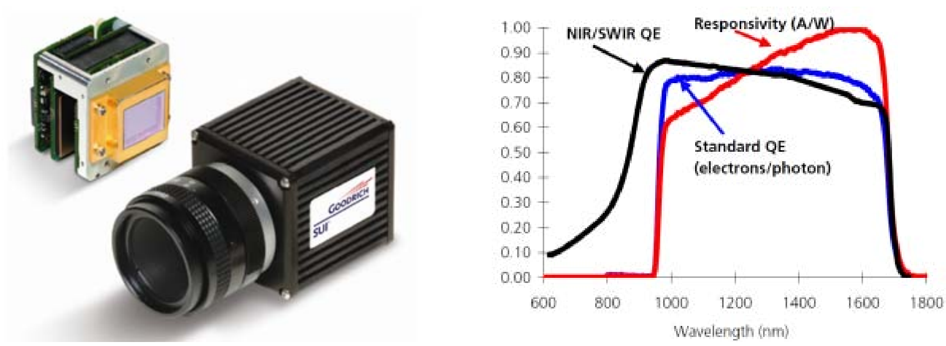


Figure 1.3 Sensors Unlimited SWIR Camera Used to Make SWIR Measurements of Sky Glow.

The SWIR camera used for the measurements was a Sensors Unlimited model 320KTX with 320x240x40 µm pixels. The camera has quantum efficiency above 60 % from 900 nm to 1700 nm as shown in the curve in figure 1.3. The effective read noise of the camera was about 50 equivalent detected photons per pixel.

SWIR image measurements shown in the subsequent sections were made using an F/1.4 50 mm focal length camera lens. With SWIR air glow irradiance levels, optics faster than F/2.5 are typically required for passive night glow imaging in order to concentrate enough light onto the detector array.

In order to make comparisons, two visible cameras were used in conjunction with the SWIR, an intensified CCD camera operated at 30 Hz, and a low noise CCD camera with 1 second exposures.

2.0 MEASUREMENTS

Image measurements were carried out at two sites, a simi-uban site about 10 miles south of Albuquerque, NM and a rural site on the west coast of the Hawaiian island of Kauai. At the Albuquerque site there is a considerable amount of ambient light from the city scattering off the bottoms of clouds. The Kauai site has very little ambient illumination other than direct and scattered moonlight. When the image measurement data was collected, the SWIR camera was mounted side by side with one of the visible cameras.

2.1 ALBUQUERQUE SITE

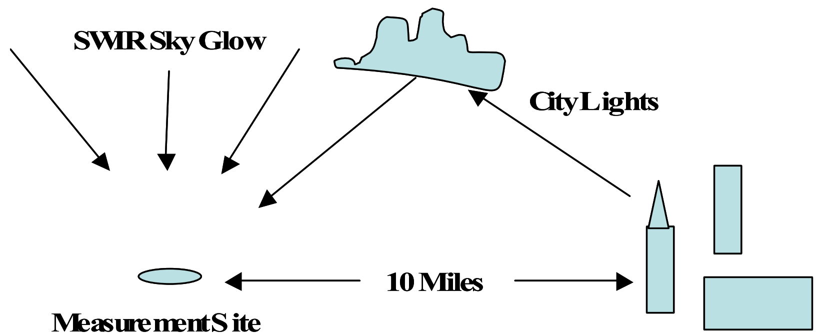
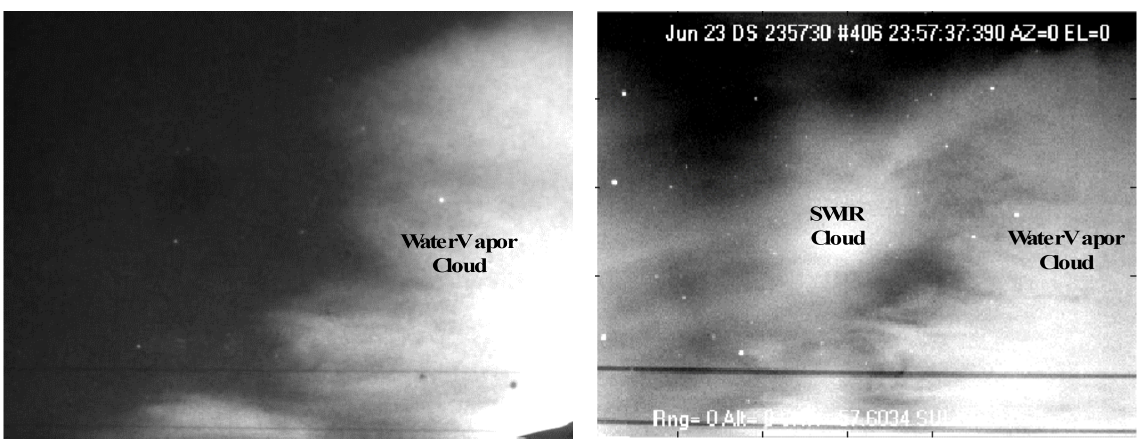


Figure 2.1 Albuquerque Semi-Urban Measurement Site

Figure 2.1 illustrates the illumination geometry of the Albuquerque test site. The measurement site was located about 10 miles south of town. We receive sky illumination directly from regions of the sky that are not blocked by clouds. We also receive indirect illumination from city light scattered off cloud bottoms.



Visible Camera SWIR Camera

Figure 2.2 Comparison of Visible and SWIR images from Albuquerque Site, -50 Deg from Zenith.

Figure 2.2 illustrates the comparison between visible and SWIR band images. In the visible band we see a water vapor cloud which scatters ambient city light. In the SWIR band we see the same water vapor cloud, but in addition we can see regions of sky glow that don't show up in the visible image.

Zenith Angle	**SWIR SKY Glow Radiance Albuquerque Test Site**
-80	**$2.9x10^{-8}$ W/cm2**
-50	**$2.1x10^{-8}$ W/cm2**
-10	**$4.2x10^{-9}$ W/cm2**
0	**$3.5x10^{-9}$ W/cm2**

Table 1 Sky Glow Irradiance Measurements as a Function of Zenith Angle Albuquerque Site.

The sky glow occurs in a layer of the atmosphere about 80 km above the ground. Simple geometric arguments can be used to show that as one looks closer to the horizon, the line of sight traverses a longer path through the sky glow gases. This means that one expects the sky glow irradiance to be greater from observations looking near the horizon as from observations looking near zenith. Table 1 shows the measured sky glow irradiance as a function of zenith angle. This table shows almost an order of magnitude difference in irradiance between observations made near the horizon on those made near zenith.

Visible Camera SWIR Camera

Figure 2.3 Comparison of Night Time Imagery from SWIR and Intensified Visible Cameras, Albuquerque site.

Figure 2.3 shows a comparison of imagery obtained from the SWIR camera alongside an image from the intensified CCD camera. The images were taken at 12 pm with no solar or moon illumination. The intensifier was turned up in order to obtain the visible image from a low level of illumination produced from city light scattered off the cloud bottoms. As a result there was a large amount of scintillation noise in the image. On the other hand the SWIR image with 1/30 second exposure clearly shows details of the scene.

2.2 KAUAI SITE

We next consider the Kauai measurement site. This site is located on the west coast of the island with very little in the way of ambient street or housing light pollution. When the moon is not out, the only source of illumination is from the sky glow. The measurement site is near the edge of the ocean. Under the right conditions, it appears that we can observe sky glow reflection off the sea surface. Figure 2.4 illustrates this situation.

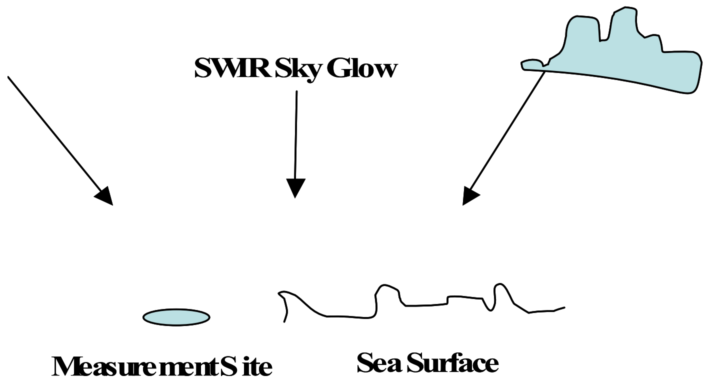
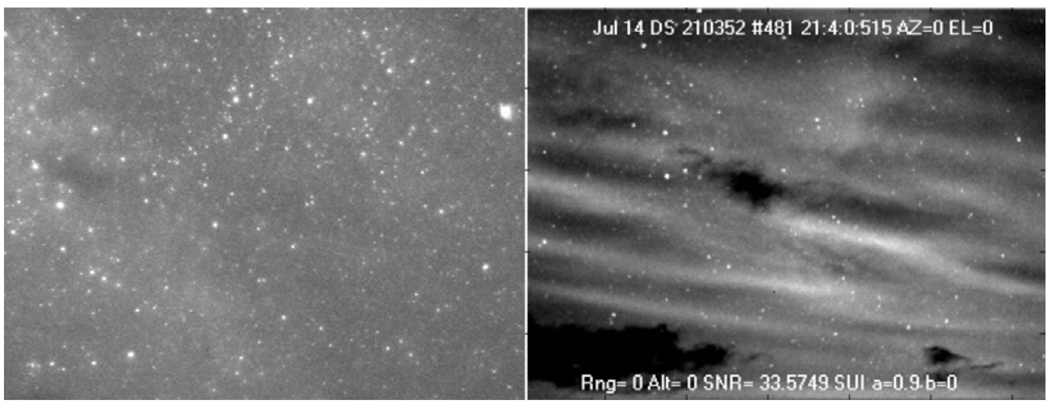


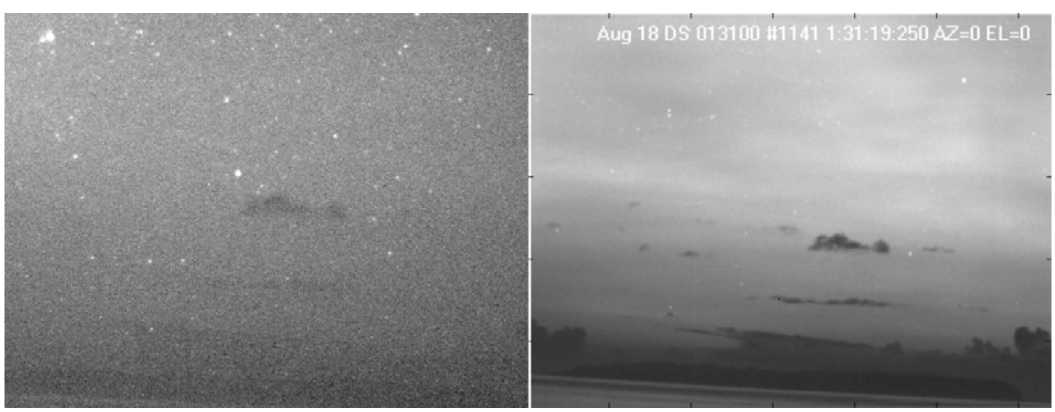
Figure 2.4 Kauai Rural Measurement Site



Visible Camera SWIR Camera

Figure 2.5 Comparison of Visible and SWIR images from Kauai Site.

Figure 2.5 shows some interesting intense striations in the sky glow radiance from the Kauai site. The irradiance from these striations was about 4.1×10^{-8} Watts per cm^2.



Visible Camera SWIR Camera

Figure 2.6 Sky Glow Measurements Near the Horizon.

Figure 2.6 shows sky glow measurements made near the horizon with the island of Niihau in the background. It can be seen from the visible camera data that there is very little ambient illumination.

Zenith Angle	SWIR SKY Glow Irradiance Kauai
-85	**$3.9x10^{-8}$ W/cm^2**
-80	**$2.3x10^{-8}$ W/cm^2**
-75	**$2.5x10^{-8}$ W/cm^2**
-65	**$1.3x10^{-8}$ W/cm^2**
-35	**$4.6x10^{-9}$ W/cm^2**
-20	**$4.5x10^{-9}$ W/cm^2**
0	**$8.0x10^{-9}$ W/cm^2**

Table 2 Sky Glow Radiance Measurements as a Function of Zenith Angle Kauai Site.

3.0 CONCLUSIONS

Chemical luminescence from excited hydroxyl radicals in the upper atmosphere at about 80 km provides a natural illumination source for night time imaging in the SWIR band between 1.0 and 1.7 µm. A series of image measurements have been made of sky glow radiation at two measurement sites, one outside of Albuquerque, and a second on the west coast of Kauai, Hawaii. The irradiance levels measured were consistent with published levels as shown in figure 3.1

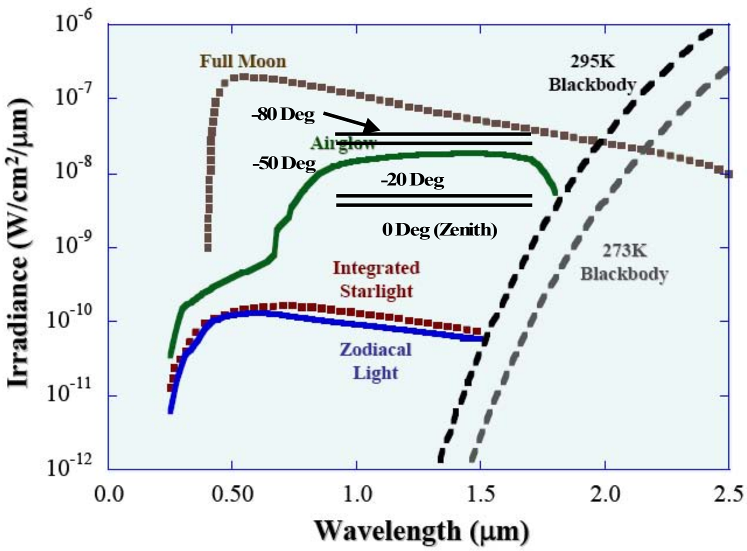


Figure 3.1 Night Time Illumination Sources With Sky Glow Measurements Superposed.

Comparisons between measurements with a SWIR camera and ones made with a visible camera show that significantly improved imagery can be obtained at night with passive SWIR cameras. The SWIR images were obtained with an F/1.4 lens. The irradiance levels from the sky glow require fast optics, less than F/2.5, in order to concentrate enough light on the detector pixels. This results in low spatial resolution at long ranges.

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